(12) UK Patent Application (19) GB (11) 2 243 961 (13) A

(43) Date of A publication 13.11.1991

(21) Application No 9105069.0

(22) Date of filing 11.03.1991

(30) Priority data
(31) 9005300 (32) 09.03.1990 (33) GB

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(51) INT CL⁵
H02M 3/04 // H02J 7/00, H02M 3/156

(52) UK CL (Edition K)
H2F FXT F9H6 F9J20 F9K1 F9K12 F9Q F9T6 F91DD F91DZ F91NL F91TR
H2H HAPA HAPC HAPD HBCD HBCJ H24R H25G
U1S S1171 S1827 S1928 S2078 S2188 S2192

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EP 0135190 A1 US 4594541 A
US 4594541 is equivalent to EP 0135190

(58) Field of search
UK CL (Edition K) G3U UAA1B UAE9, H2F FXS FXT FXX
INT CL⁵ H02M

(54) DC-DC Power supply circuit

(57) In a power supply circuit especially in a battery charger for a battery for a golf trolley a forward switching step-down converter circuit embodies a high speed switching device 26 in the low DC line, along with an energy storing inductor 28, and the low line is coupled to the high line through a diode 30 connected to the low line between the high speed switching device and the storage element. The switching device 26 can be on for 100% of the total duty cycle so as to operate in the linear mode. When charging a discharged battery initially PWM controller 42 is controlled by an output from amplifier 56 as long as its output exceeds a predetermined value and an amber LED 76 is illuminated. When the output from amplifier 56 is below this value the pulse width control is by means of the output from amplifier 46. When the output of amplifier 56 falls below a further value transistor 66 turns off and circuit 69 is excluded from circuit 49, the output voltage falls to a trickle charge, amber LED 76 is turned off and a green LED 78 is turned on. A thermistor 68 provides temperature compensation and overvoltage protection is obtained by 34, 38, 40 and 57.

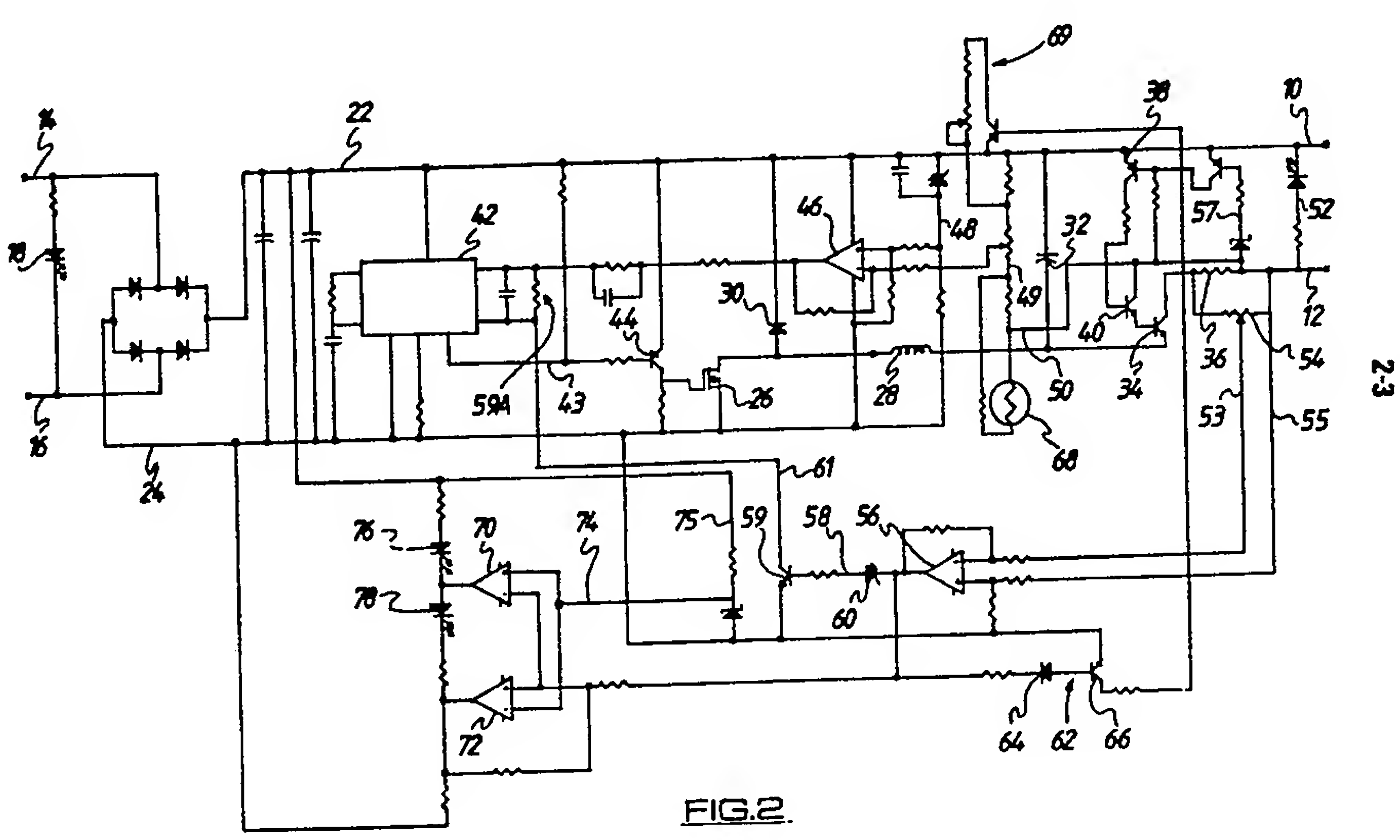

FIG.2.

The specification as filed includes textual matter, included with the drawings originally filed, which is not reproduced here; it may be inspected in accordance with Section 118 of the Patents Act 1977.

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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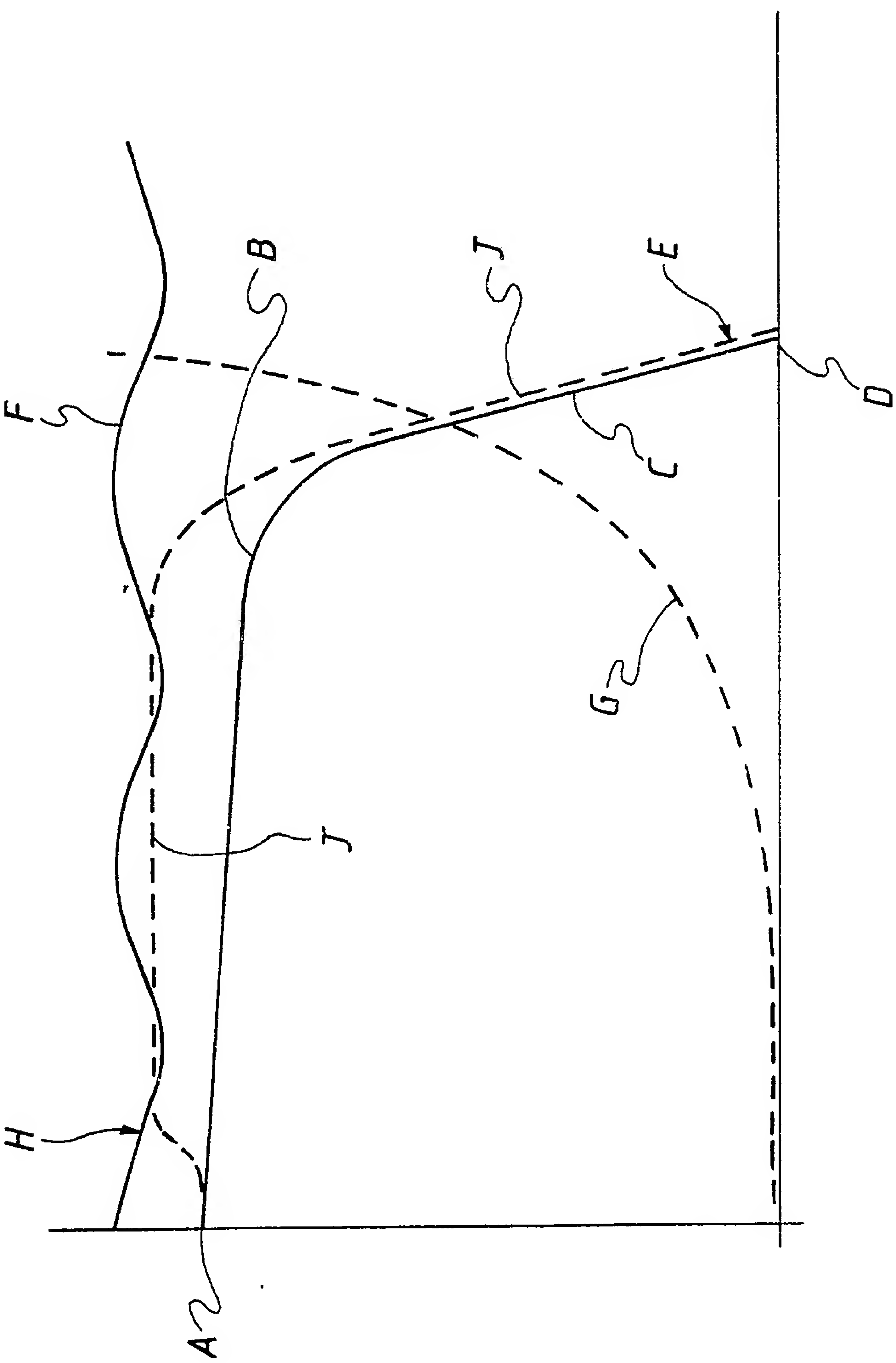

FIG.1

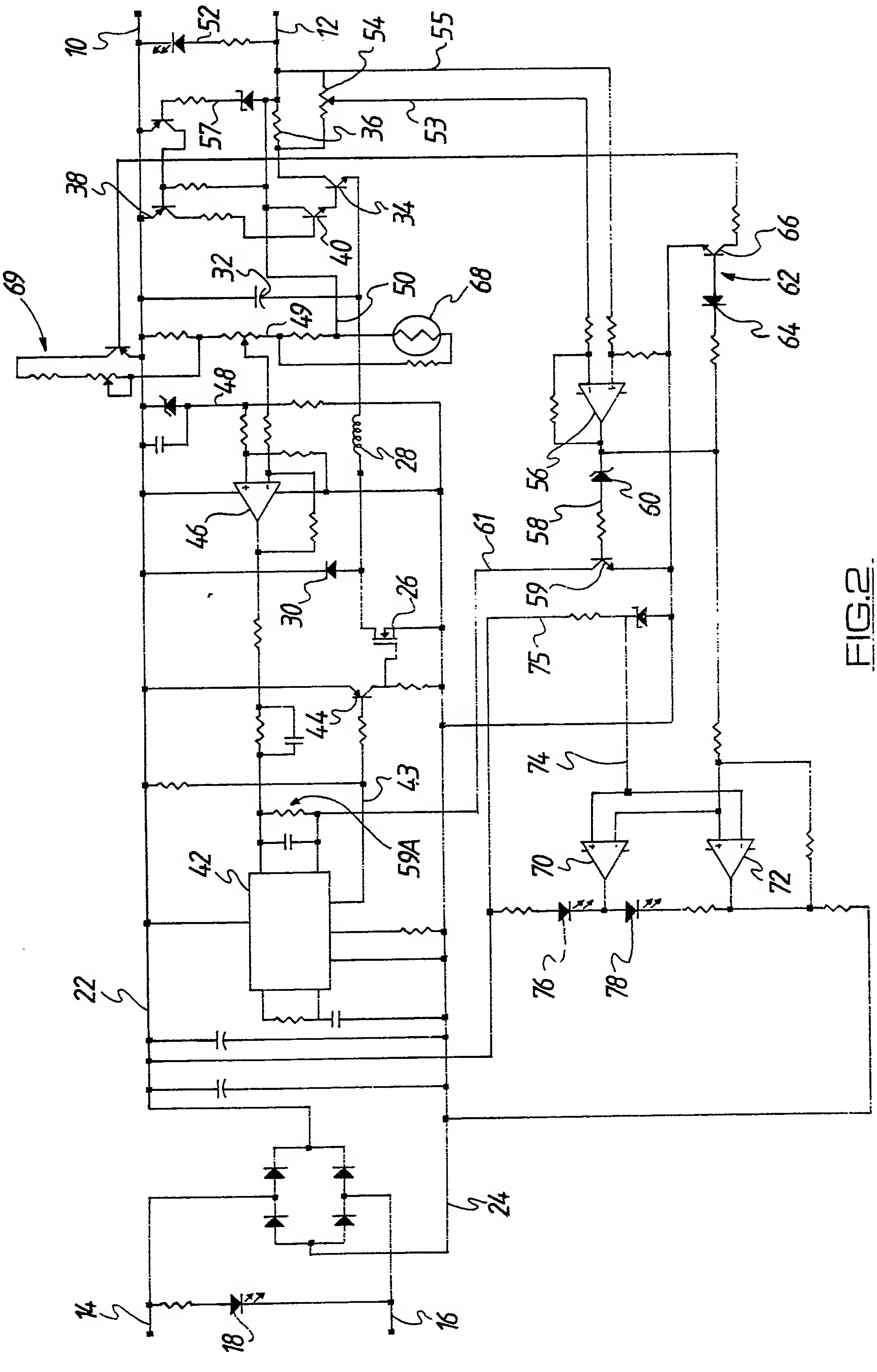
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FIG.2

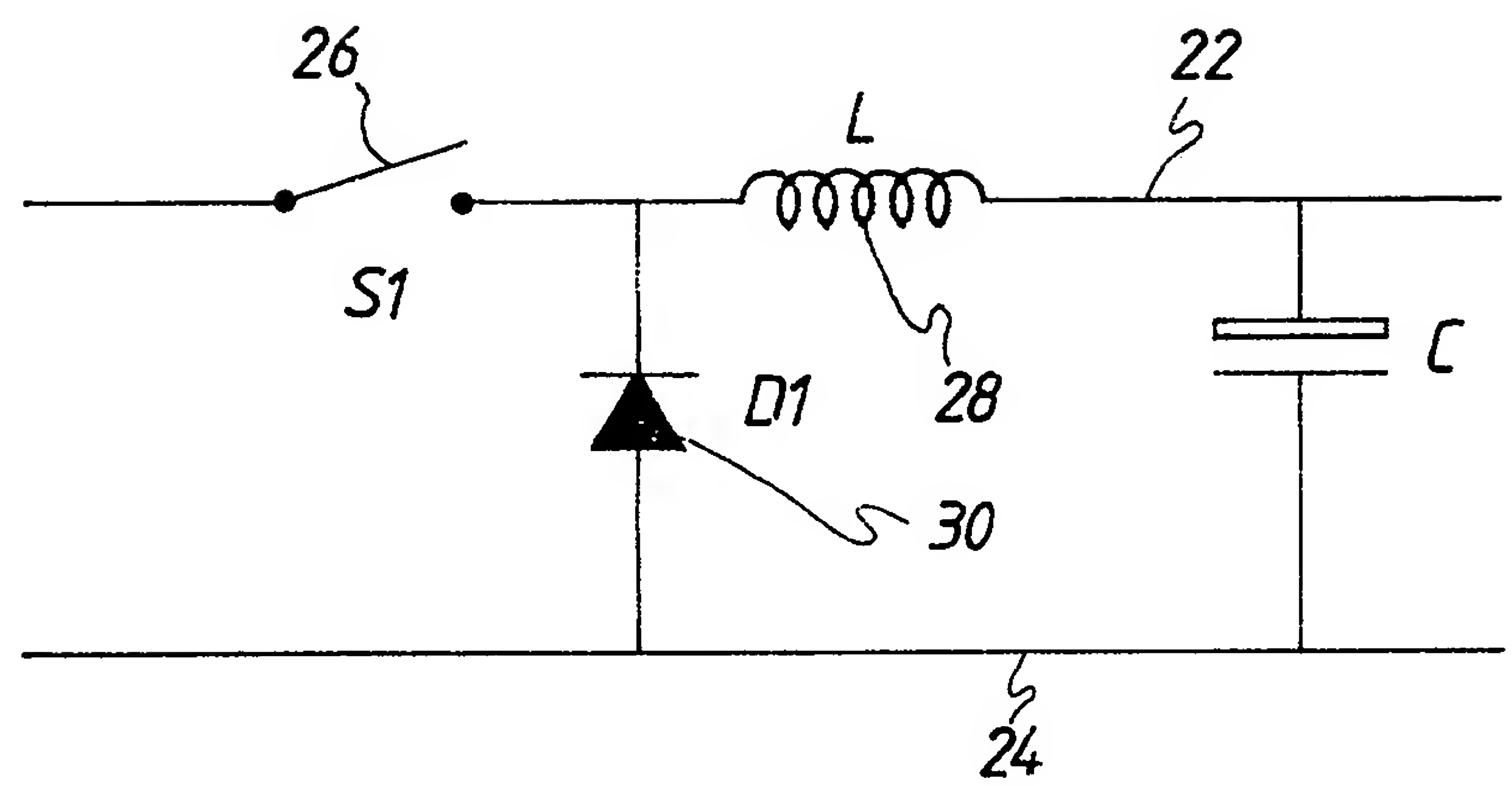

FIG.3

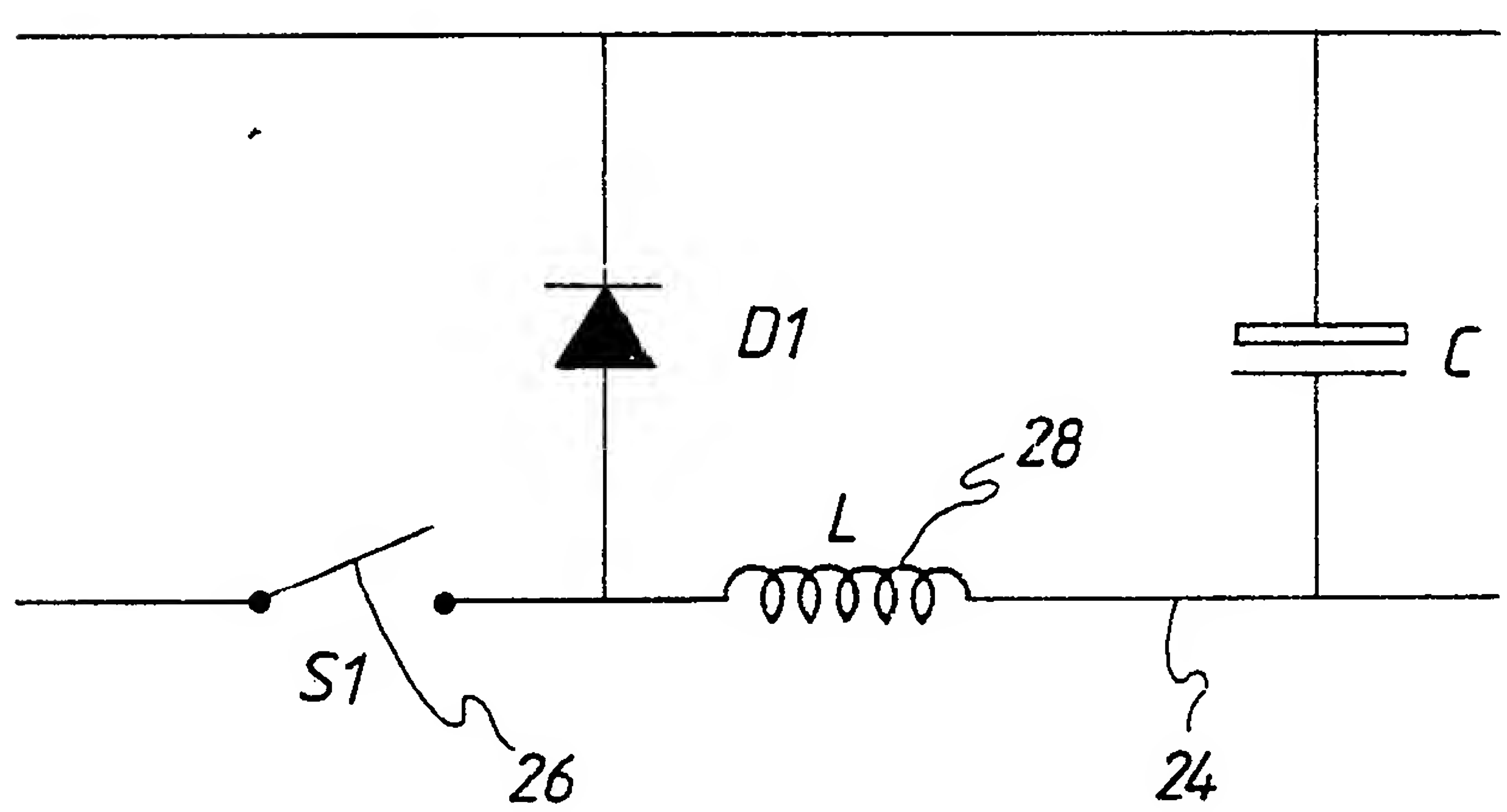

FIG.4

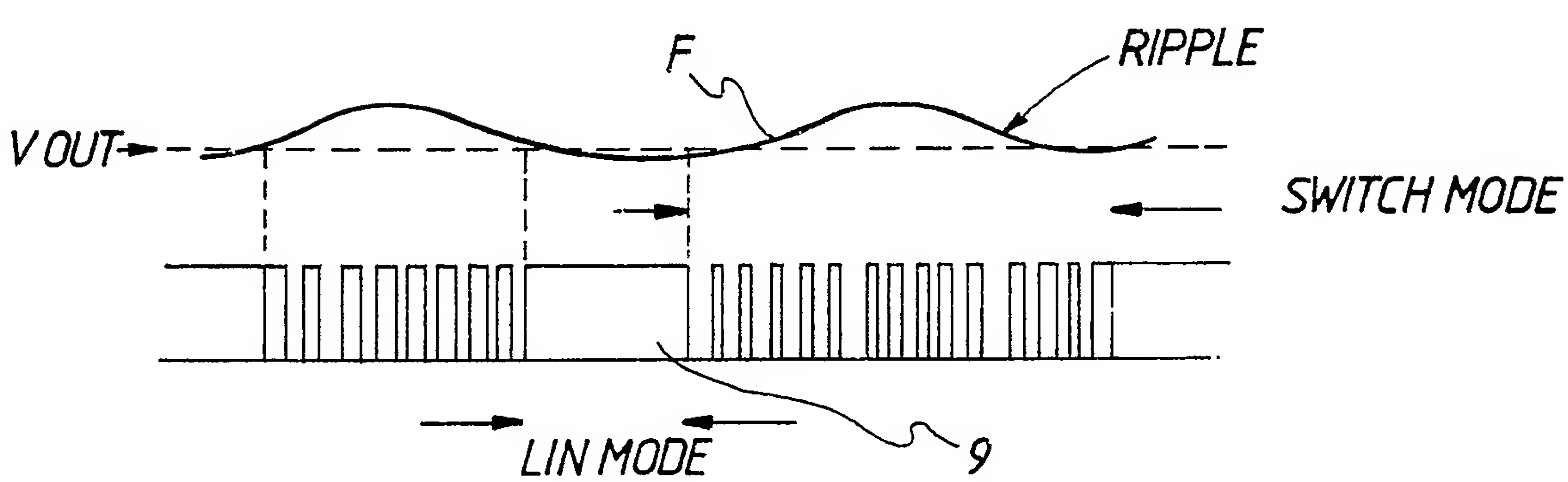

FIG.5

POWER SUPPLY CIRCUIT

This invention relates to to power supply circuits, and relates particularly but not exclusively to power supply circuits for use in the charging of sealed lead acid batteries such as may be used for example in lighting systems, fire alarms, security systems, stand-by lighting, back-up power supplies, golf trolleys, T.V. equipment and the like.

In a particular application, the power supply circuit is embodied in a battery charger for a golf trolley, but the invention is not to be considered as being limited thereto, although specific reference is made hereinafter to battery chargers for the sealed lead acid batteries of golf trolleys.

Conventionally,, golf trolley batteries are charged by means of a power supply circuit which may embody a forward switching step-down converter circuit which comprises essentially a circuit having a rectified DC input leading to a high speed switching device, such as a MOSFET in the potentially high line, supplying an energy storage device such as an inductor also in the potentially high line. A diode acting as a fly wheel diode couples the two lines between the high speed switching device and the energy storage device, and an output capacitor is connected across the lines at the output. With this arrangement, when the switching device is closed, current flows into the storage element and when the switch is opened, the energy stored in the storage element is transferred to the output. The on-time of the switch is never more than 50% of the total duty cycle. Also, with this arrangement the high frequency content is used inter-actively with the storage element.

This type of circuit does have inefficiencies, and the

circuit according to the present invention can serve to reduce component cost with no detriment to the overall system operation.

By way of exemplary comparison, one form of conventional golf trolley battery charger may take over 12 hours to completely charge a deeply discharged battery, whereas with the circuit arrangement of the present invention the same result can be achieved in as little as 7 hours.

In accordance with the invention, a power supply circuit suitable for the functions referred to above embodies a forward switching step down converter circuit comprising a DC input and a DC output and in the low line is embodied a high speed switching device and also an energy storage element, and between the storage element and switching device, the low line is coupled to the high line through a diode, whilst a capacitor is coupled across the output.

With this arrangement, the input voltage need not be at the same high ratio to the output voltage as in the case of the conventional arrangement described above which means that the input transformer components for the converter circuit can be of a lower rating. Therefore the circuit according to the invention will not suffer as much from ripple effects as in the conventional arrangement.

With the arrangement of the invention, the on-time for the switch can be up to 100% of the total duty cycle, as by embodying the storage element in the low line, the circuit does not rely entirely on the energy storage of the storage element but in fact the storage element need only be utilised on low load or trickle charge conditions or when the input voltage is higher due to the regulation of the input transformer equipment. The circuit furthermore permits an

unusually high ripple voltage which means that capacitor costs can be reduced, and the circuit can cope with poor transformer regulation which again reduces costs.

A battery charger with a converter circuit according to the invention enables charging of a deeply discharged battery without the charger becoming unstable.

The invention can be applied in general where deep discharge current limitation operation is desireable; load regulation is not too critcal; and high efficiencies are attainable.

An embodiment of the invention will now be described by way of example, with reference to the accompanying drawings, wherein:-

Fig. 1 is a battery discharge characteristic curve for a sealed lead acid battery;

Fig. 2 is a circuit diagram of a battery charger according to and embodying the invention;

Fig. 3 is a circuit diagram of a conventional forward switching step-down converter circuit;

Fig. 4 is a view similar to Fig. 3, but showing how the step down converter circuit is modified in accordance with the embodiment of the invention; and

Fig. 5 is a diagram indicating the operation of the switching device as shown in Fig. 4.

Referring to the drawings, Fig. 1 shows a discharge characteristic A, B, C, D, of a sealed lead acid battery such as is used in connection with powered golf trolleys. At

position A of the characteristic, which is a graph of voltage against depth of discharge, the battery may be considered fully or 100% charged and ready for use. At position B, the battery has discharged to a relatively large extent, but if it discharges further it will fall to the position C on the characteristic, and when it reaches position D, it will be deeply discharged and indeed may be damaged beyond repair if left in this state or recharged with the conventional charger referred to above. Position E represents a nominal maximum depth of discharge which may be that the battery has an output in the order of 0.7 volts compared to a fully charged condition of say 12 volts.

The line F in Fig. 1 represents the input or unregulated line voltage of the battery charger which will be connected to the battery to recharge same. Characteristic G shown in chain dotted lines is an indication of the charging current drawn from the battery charger as the battery progressively charges from the deep discharge position E to position A.

The dotted line curve J indicates the charging potential at the output of the charger as the battery progressively recharges.

Referring now to Fig. 2 which shows the electrical circuit of the battery charger embodying the circuit according to the invention, the two output lines or terminals of the charger are indicated by reference numeral 10 (the potentially high line) and 12 (the potentially low line). The input terminals of the charger are indicated by reference numerals 16 and 14 which are connected to a transformer in order to receive single phase AC power. A power on red light emitting diode 18 is connected across the terminals 14 and 16 to show that power is connected to the circuit, and the lines from terminals 14 and 16 are connected to a full wave rectifier to

supply a DC input unregulated voltage on lines 22 (potentially high line) and 24 (potentially low line). The voltage appearing on lines 22 and 24 is the voltage indicated by line F in Fig. 1.

Line 22 is connected directly to output terminal 10, and line 24 is connected to output terminal 12 through the high speed switching device 26 which may for example be a mosfet, and an energy storage inductor 28. A diode 30 or some such other rectification device is connected between line 24 and line 22 and is connected to line 24 between the high speed switching device and the inductor 28, and a capacitor 32 is connected between lines 22 and 24 as shown. Line 24 between the output terminal 12 and the coupling thereto of capacitor 32 is provided with a transistor 34 forming an on/off switch device, and a potential dropper resistor 36 for providing output signals ,to a current limiting device.

Reference numeral 38 represents a switch on transistor connected between line 22 and an intermediate switch transistor 40 which in turn controls transistor 34.

The mosfet high speed switching device 26 is driven by a pulse width modulator 42 which turns on a transistor 44 as long as there is an output from switch 42 on line 43. When transistor 44 is switched on, mosfet 26 is switched on. The pulse width modulator is driven from an error amplifier 46 having two inputs respectively controlled by a voltage dropping circuit 49 providing a potential proportional to the output potential on terminals 10 and 12, and a circuit 48 providing a fixed voltage of 4.7 volts as a reference. When the output on terminals 10 and 12 is such as to provide an output from circuit 49 which deviates from the reference voltage 48, an error signal is outputted from the amplifier 46 to the pulse width modulator 42. The circuit 49 is driven

from an output connecting wire 50 which is coupled to the output terminal 12.

A red light emitting diode is also connected across the output 10 and 12 as indicated by reference 52. This is to indicate when the output 10, 12 is reversely connected to a battery to warn the user to change the terminals.

Connected across resistor 36 is a potentiometer 54, the pointer 53 and one end terminal 55 of which are connected to an amplifier 56. The output line 58 of the amplifier 56 is provided with a zener diode 60 and said output line 58 carries an output which is proportional to the current supplied to the battery during charging.

The output 58 is connected to a transistor 59 which in turn is coupled in line 61 which provides an overriding control input to the pulse width modulator. The output of the error amplifier 56 also controls a switch circuit 62 comprising zener diode 64 and transistor 66. Transistor 66 is connected to a two-stage control circuit 69 controlling the output of the circuit 49 providing an input to the error amplifier 46 so that the charger has two distinct stages of operation as will be described. It should be mentioned also that the circuit 49 embodies a thermistor 68 so that the output of circuit 49 can be compensated depending upon the temperature.

The output from amplifier 56 also provides one of the inputs of each of two comparators 70 and 72, the other input of which is a fixed reference voltage of 1.2 volts applied on line 74 via a voltage dropping circuit 75 connected across the terminal 22 and 24 and embodying a zener diode and voltage dropping resistance.

The outputs from the error comparators 70 and 72 are coupled

to a series circuit embodying an amber light emitting diode 76 and a green light emitting diode 78 coupled in series as shown.

The general operation of the battery charging circuit shown in Fig. 2 operates as follows. Assume that the battery to which the circuit is to be connected is deeply discharged i.e. to the position E shown in Fig. 1. The terminals 14 and 16 are connected to the AC power supply, and the light emitting diode 18 is illuminated. The terminals 10 and 12 are connected to the battery terminals. If the output terminals 10 and 12 are connected to the wrong polarity battery terminals, the LED illuminates, the transistor 38 is switched off, which switches off transistors 40 and 34, and there is no operation of the circuit. When the terminals are correctly connected, the transistor 38 switches on transistor 40 which in turn switçhes on transistor 34. The circuit 57 incidentally which is connected across the output embodies a transistor which is coupled to transistor 38 and provides for over voltage protection. If an over voltage is applied, the control transistor cuts off transistor 38 which in turn cuts off transistors 34 and 40.

Initially, when the battery is deeply discharged as shown in Fig. 1, by position E, the battery will draw a high current at low voltage, and a voltage proportional to the current drawn by the battery appears across resistor 36. Circuit 48 continues to output the fixed voltage, whilst the circuit 49 outputs a voltage which is proportional to the output voltage on terminals 10 and 12. Because circuit 49 as will be explained is adapted to output two voltages which have different proportionality to the output voltage, in this stage of operation in the output from the circuit 49 is referred to as the first stage operation voltage. The difference between the fixed voltage from circuit 48 and the

first stage output voltage from circuit 49 causes an error voltage to be outputted from amplifier 46 which in turn is coupled to the pulse width modulator 42. This output would in the normal course of events cause the pulse width modulator to output wide pulses corresponding to the high demand from the battery, but the circuit 56, 60, 58 and 59 overrides the error amplifier input so as to provide short output pulses on the pulse width modulator to ensure that the switching device 26 outputs narrow width pulses. The circuit 56, 60, 58 and 59 effects this control in that the voltage appearing across the input of amplifer 56 at this time is relatively large because of the large charging current through resistor 36, and the output from amplifier 56 is greater than 5 volts which therefore breaks down zener diode 60, and the output on line 58 causes transistor 59 to switch on. The circuit 59A is therefore pulled low and this overrides the output from the amplifer 46.

The output from amplifer 56 also breaks down the zener diode 64 which is a 3 volt unit, causing conduction of the transistor 66 and in turn causing the circuit 69 to be embodied in the circuit 49 to provide the first stage output voltage from circuit 49.

The charging continues along the graph J in Fig. 1, until, by virtue of the reduction in the current drawn by the battery, the voltage on lines 53 and 55 to amplifier 56 is such that the output from the amplifer 56 drops below 5 volts and the zener diode 60 is no longer broken down. Transistor 59 switches off, and the pulse width modulator is now controlled by the output of the error amplifier 46. It should be mentioned furthermore that as long as the output from amplifier 56 is greater than the 1.2 volts rating of the zener diode in circuit 75, the amber light 76 remains illuminated, and the green light 78 remains extinguished.

The output voltage has now reached the stage where the characteristic J interferes with the waves of the ripple on unregulated voltage F as shown in Fig. 1 and as shown in Fig. 5. As long as the characteristic J does not intersect the voltage ripple, then the error output from amplifier 46 controls the width of the pulses from pulse width modulator 42, and high frequency pulses pass through the switch 26 continuing the charging of the battery.

When position H is eventually reached in the charging cycle, the output from amplifier 56 falls below 3 volts, and the zener diode 64 is no longer broken down. Transistor 66 turns off, and circuit 69 is excluded from the circuit 49, which outputs the second stage output voltage, and the output voltage falls towards position A. Between positions H and A, a trickle current flows into the battery providing the final charging operation. When the output from amplifier 56 eventually drops as low as 1.2 volts, the comparators 70 and 72 change state, and the amber light 76 is extinguished and the green light is illuminated indicating that the battery is fully charged.

The unregulated voltage F has a singificant ripple as shown in Fig. 5 and the switch 26 only remains on continuously as shown in Fig. 5 at reference 9 until the ripple in the unregulated voltage takes the unregulated voltage above the output voltage on terminals 10 and 12. This linear mode can be introduced by the embodiment of the switching device 26 in the low potential line in conjunction with the inductor 28 as will be explained. Charging continues until region H is reached which is in fact the stage at which the electrolyte in the battery may tend to reach the gassing stage. It is a manufacturer's recommendation that at stage H, the charger should move into the second stage of charging in that because the error signal from amplifier 56 is now so low due to the

small charging current, the zener diode 64 is no longer overcome and transistor 66 ceases conducting which isolates the two stage charging circuit portion 69 in circuit 49 and a new drive voltage from circuits 49 is established which is proportional to the voltage rating (13.8 or 20^{o}C) of the battery and the charging continues along the dotted line as indicated in Fig. 1 until the fully charged condition is met. Condition H is not reached until the battery is approximately 95% charged. Finally, when the output of the amplifier 56 reaches 1.2 volts the comparators change state extinguishing the amber LED 76, and illuminating of the green LED 78 indicating that the battery is now ready for use. At this stage the trickle current is in the region of 200/500 mA.

The circuit described is enhanced according to the invention by the use of the basic converter circuit shown in which the high speed switching device 26 is embodied in the low line 24, as is the inductor 28. Conventionally, these circuit elements are arranged in the high line 22 as shown in Fig. 3.

The circuit shown in Fig. 3 is a conventional forward switching step down converter used in battery chargers. In the circuit of Fig. 3, switch 26 is closed and opened at high frequency e.g. in the order of 25 to 300 kH, and when the switch is closed current flows into the storage inductor 28, into the output C and into the load. When switch 26 opens, the energy stored in the inductor is transferred to the output, but the time during which the switch is closed is never greater than 50% of the total duty cycle. Diode 30 acts as a flywheel diode and serves to clamp the inductor to the low or negative rail 24, which ensures effective delivery of the energy from the inductor instead of it manifesting itself as a large -L di/dt. Conventionally therefore the high frequency content is always used interactively with the storage inductor 28.

The conventional circuit of Fig. 3 is used to step down voltages at high efficiencies, but this method requires the use of large inefficient mains transformers since, in sealed lead acid battery charging, high input voltages at comparatively high currents are required as are higher voltage rated switching elements.

In the arrangement of Fig. 4 which shows an embodiment of the invention however, switching devices 26 can be on for up to 100% of the total duty cycle and as explained herein can operate in the linear mode 9 as illustrated in Fig. 5 because the circuit does not rely entirely on the energy storage of inductor L. The inductor L in fact is only utilised on low loads between the regions A and H in Fig. 1 or when the input voltage is higher due to the regulation of the input transformer. The circuit of Fig. 4 has the advantage of being usable with an unusually high ripple voltage which results in low capacitor costs. It has the ability to cope with poor transformer regulation again reducing costs.

The utilisation of the circuit of Fig. 4 results in high efficiencies in the order of 95% at full load and 55% at deep discharge current limit. At deep discharge current limit the product of voltage times current is low which means that although there is 45% loss there is in fact low dissipation.

The circuit of Fig. 3 provides advantages of over voltage protection reverse battery protection, short circuit protection, over temperature protection, thermal compensation, and two stage charging.

CLAIMS

1. A power supply circuit in the form of a forward switching step-down converter comprising a DC input and a DC output, and in the low line is embodied a high speed switching device and also an energy storage element, and between the storage element and the switching device, the low line is coupled to the high line through a rectification device.

2. A power supply circuit according to Claim 1, wherein the on-time for the switching device can be up to 100% of the total duty cycle.

3. A power supply circuit according to Claim 2, wherein the switching device operates in linear mode and switch mode and in linear mode the output voltage exceeds the ripple unregulated input voltage, whereas the input voltage exceeds the output voltage in the switch mode, and the on-time for the switching device is 100% of the total duty cycle during the linear mode.

4. A power supply circuit according to Claim 1, 2 or 3, wherein a capacitor is coupled across the DC output.

5. A power supply circuit according to any preceding Claim, wherein the energy storage element is an inductor.

6. A power supply circuit according to any of Claims 1 to 5, wherein the high speed switching device is a mosfet.

7. A power supply circuit according to any preceding claim, when embodied in a charger for a sealed lead acid battery.

8. A power supply circuit according to Claim 7, wherein the lead acid battery is a 12 volt battery for golf trolleys.

9. A power supply circuit according to any preceding claim, including any feature or combination of features as described hereinbefore with reference to the accompanying drawings.

10. A power supply circuit substantially as hereinbefore described with reference to the accompanying drawings.

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